Review Articles

Life Cycle Assessment in the Telecommunication Industry: A Review

Wolfram Scharnhorst

Swiss Federal Laboratories for Materials Testing and Research, Überlandstrasse 129, 8600 Dübendorf, Switzerland
(Wolfram.Scharnhorst@empa.ch)

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Abstract

Background, Goal and Scope. Today, after the technologically and commercially successful breakthrough of electronic telecommunication facilities, rapid and globally untrammelled information exchange has become an indispensable service in daily life. Associated with the tremendous growth in electronic telecommunication hardware (GSMAssociation 2005), however, was and continues to be an increasing awareness of the environmental effects related to both the operation and the production, as well as the End-of-Life (EoL) treatment of such communication equipment. Environmental concerns, for example, have resulted in various governmental regulations such as the WEEE- (CEC 2003b) and the RoHS-directives (CEC 2003a).
To analyse, interpret and improve the environmental performance of electronic telecommunication equipment, life cycle assessment (LCA) is increasingly recognised as one promising analytical tool. Based on a thorough review of the scientific work and by discussing industrial views, this paper is intended to determine the key milestones achieved, to analyse the current research situation and to outline the key challenges concerning LCA and electronic telecommunication industries.

Method. Starting with a brief reflection of the LCA approach, the particularities in context with telecommunication products[1] are discussed. Exemplary for various stakeholders participating in the supply chain of telecommunication means recent industry perspectives are also presented.

Results. In the core section of the proposed paper, the pertinent scientific literature on LCA and electronic telecommunication means is reviewed and the most impressive achievements are documented. Particular attention is dedicated to subcomponents of individual electronic telecommunication devices (e.g. Printed Wiring Board Assemblies (PWBA) of mobile phones), components of mobile communication networks (e.g. Base Transceiver Stations (BTS)) and entire networks concentrating on product comparisons, inventory approaches, impact assessment method development, result interpretations and presentation, and usability of LCA in decision-making.

Discussion. From the reviewed scientific literature and industry views, it was found that telecommunication products, in general, represent complex objects requiring a well thought-out performance of the LCA tool. It has been shown that today there is a lack of stakeholder involvement resulting in LCA studies which only partly fulfil the expectations of the contractors. In this spirit it was recognised, at present, that most of the LCA studies on telecommunication equipment result in bulky and stakeholder unspecific compilations of findings impossible to be used in rapid decision-making. This aspect may explain why LCA so far is not or only partly integrated into decision-making of globally integrated industries, such as in telecommunication industries.

Conclusions. In summary, it can be stated that LCA represents a promising alternative to analyse, to interpret and essentially to adjust the environmental performance of electronic telecommunication products. The review showed that there is a need to focus research efforts in order to arrive at sound improvements of the LCA methodology.

Perspectives. The conclusions from the presented review suggest concentrating in particular on further development of the LCA methodology with respect to efficiency, effectivity and flexibility. This challenge is associated with the need for LCA to be understood as a process rather than a discontinuously applicable tool, attending industrial processes, in essence to contribute to improved environmental performances of products. In this context, particular attention should be paid to proper stakeholder involvement and continuous exchange of concentrated information relevant for the respective stakeholder.

Keywords: End-of-Life; GSM; ISO; life cycle assessment; telecommunication; UMTS

Introduction

In its broadest sense, the term *telecommunication* grasps any kind of remote information exchange between two or more participants by means of mechanical and/or electrical/electronic utilities including wired and mobile telephony, E-mail, World Wide Web, Fax, television, etc. (ANSI 1994). This diversity results in a highly heterogeneous industry sector. The review on the application of life cycle assessment (LCA) to telecommunication products compiled below cannot cover the whole breadth, but concentrates on the communication infrastructure and software products, i.e. data transfer services, in the mobile and wired telephony branch. Other telecommunication branches are examined if relevant.

Key service of the telephony industry, is still the transmission of voice between two or more participants. Wired telephony dominated the telephony market in terms of subscribers till the end of the past century (ITU 2006a). However, since the technologically and commercially successful breakthrough of the GSM standard in the early 1990s, there is a distinct trend to replace fixed telephony with mobile systems (**Table 1**). This tendency is further enhanced by the ongoing transition from the GSM to the Universal Mobile Telecommunication System standard (UMTS). For instance, the number of mobile phone subscribers is about 1.7 times higher than those of fixed phone subscribers (GSMAssociation 2006a, ITU 2006a).

[1] According to ISO 14040ff. ISO (1997): ISO 14040: Ökobilanz – Prinzipien und allgemeine Anforderungen. International Organisation for Standardisation, Brussels the term product covers both product systems as well as service systems.

Table 1: Mobile and fixed phone subscriber statistics (in million), revenues (total and in billion US $) and traffic data (total) taken from (GSMworld 2006, ITU 2006b, Schulzrinne 2006) ('–' indicates that no data were available). The values given for 2006 reflect the situation at the end of the second quarter (GSMAssociation 2006b)

	Year														
Subscribers	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
GSM	0.2	1.4	5.0	13.0	32.8	71.1	138.4	258.4	456.1	626.2	790.6	1012.0	1296.0	1709.2	1941.6
W-CDMA	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	2.8	16.3	50	74.7
TDMA	0.0	0.0	0.0	0.1	0.7	2.6	6.3	15.9	38	67.6	108.1	110.6	90	48.5	26.1
PDC	0.0	0.0	0.5	3.3	13.9	26.8	38.1	44.8	50.8	56.8	60.1	58.1	54.2	46.3	38.5
iDEN	0.0	0.0	0.0	0.0	0.3	1.4	3.1	5.1	8.2	11.1	13.6	13.4	16.8	21.1	23.8
CDMA	0.0	0.0	0.0	0.0	1.0	7.4	22.4	52.6	80.3	110.9	144.1	187.0	87.4	62.4	37.0
CDMA2000 1X	–	–	–	–	–	–	–	–	–	–	–	80.1	131.9	213.1	225
CDMA2000 1xEV-DO	–	–	–	–	–	–	–	–	–	–	–	4.6	12.3	21.2	34.5
Mobile (total)	0.2	1.4	5.5	16.4	48.7	109.3	208.3	376.8	633.4	872.6	1116.7	1468.6	1704.9	2171.8	2401.2
Revenue (US $)	26	35	50	78	114	142	172	223	278	317	364	414	454	–	–
Fixed (total)	546	572	604	643	689	791.54	837.83	908.07	979.19	1053	1086.4	1132.6	1206.2	1264	–
Revenue (US $)	350	359	386	428	444	437	456	476	477	479	478	475	552	–	–
voice traffic (Gb/s)	–	–	–	–	948	1107	1294	1511.00	1766	2063.0	2411	–	–	–	–
data traffic (Gb/s)	–	–	–	–	135	273	588	1572	4451	11328	27645	–	–	–	–

Associated with the increase in mobile phone subscribers and in networks (see Table 1) was and continues to be an increasing awareness of the environmental effects related to the operation, the production and the EoL-treatment of the communication hardware[2]. For example, though little is still compared with the jewelry industry (gold consumption in the jewelry industry is about 64% and in the electronics industry about 8.4%), for instance, the amounts of precious metals like gold, silver and palladium used in the PWBA of mobile phones, for example, distinctively contribute to a reduction of the natural resources of these metals (WGC 2006). This situation is comparable with the depletion of crude oil related to the production of the base materials such as epoxies for and the energy intensive manufacturing of Printed Wiring Boards (PWB; about 17% of the total global annual petroleum production in 2002 was consumed for other than transportation and heating processes (EIA 2003)). Both, as well as other rather production-sided concerns, induced a substantially increasing awareness with respect to the environmental consequences associated with the EoL-phase. It has been recognised that improper EoL-treatment of electric and electronic telecommunication equipment can result in a loss of useful materials which, depending upon concentration and state, can cause undesirable, i.e. hazardous, environmental effects ('Loss' in this context means that materials, once released from a product or product assembly to the environment, cannot be assessed again in an economic and environmentally safe way, whereas 'useful' stands for materials that cover all kinds of naturally existing (e.g. crude oil, metals, ceramics) and artificially generated materials (plastics, alloys, etc.)). In this context, particular attention has been paid to the volatilisation and release of heavy metals during thermal EoL-treatment of electric and electronic scrap (Scharnhorst et al. 2006c).

At governmental level these and related environmental concerns have resulted in various regulations such as WEEE (CEC 2003b) and RoHS (CEC 2003a), which aim to prevent the disposal of electronic and electric scrap as well as the use of potentially hazardous materials in electric and electronic components. Similar efforts seek to foster a reduction of the energy consumption of electric and electronic products (CEC 2005a).

In order to analyse, interpret and improve the environmental performance of products, LCA complying with the ISO-14040 standards series (ISO 1997, ISO 1998a, ISO 1998b, ISO 2005b) is increasingly recognised by scientists, consultants as well as by the industry as a promising tool to assess environmental effects (ERICSSON 2006, Koller 2005, KYOCERA 2006, Nokia 2004, Stark 2005). However, the key qualification of being a *holistic* tool makes LCA difficult and requires highly sophisticated skills by the practitioner to handle and adjust the method. Accordingly, research is being carried out continuously to improve the applicability of the LCA-approach for complex products such as telecommunication hardware.

The compiled review below is structured into an introduction followed by a brief methodological recapitulation of the LCA approach in context with electronic telecommunication. Thereafter, recent perspectives of various key industrial players are recapitulated. Subsequently, the pertinent scientific literature on LCA applied for telecommunication products is reviewed. The results of the review are then discussed, recommendations are formulated and conclusions are drawn. The review is finalised by the identification of the key challenges for ongoing and future LCA research.

[2] However, it might be worth denoting here the survey on impact and issues associated with new communication technologies, for instance. Marien, (1996): New communications technology. Telecommun Policy 20 (5) 375–387 illustrates, it was not obvious to the scientific community to debate the potential environmental implications of telecommunication equipment until the mid 1990s.

1 Method, Stakeholders and the Different Views of LCA

The LCA method is not described in detail as there exist numerous valuable sources documenting the technical and practical details and aspects of LCA in-depth (Barnthouse et al. 1997, Boustead 1996, Ekvall et al. 2001, Fink 1997, Gluch et al. 2004, Guinée et al. 2001, ISO 1998a, ISO 1998b, ISO 2005a, ISO 2005b, Jolliet et al. 2003, Rebitzer et al. 2004).

However, as will be obvious from the following analysis of the available LCA studies on telecommunication products, it is worth noting that a complete and ISO-standard conform LCA study comprises four steps: the goal and scope definition, the inventory step (referred to as life cycle inventory (LCI)), the impact assessment step (referred to as life cycle impact assessment (LCIA)) and, finally, the interpretation step[3]. The objective of an LCA, in general, is

a) to help to identify environmentally more preferable base material and/or processing alternatives,
b) to assist in industrial, governmental and non-governmental, decision-making processes,
c) to provide for useful environmental performance indicators, and
d) to assist in marketing (ISO 2005a).

A difficulty of an LCA for telecommunication products consists of the largely differing stakeholder interests driven by the very heterogeneous sub-product compositions. For example, there exist different stakeholder views along the supply chain of a mobile phone at a horizontal level (i.e. up- and downstream to the supply chain), as well as at a vertical level, i.e. in the different departments (in-house) of an individual stakeholder.

Being one of the forerunners in industrial implementation of life cycle thinking in the electronics industry sector; the Japanese company KYOCERA already successfully established a so-called 'Kyocera Green Committee' (KYOCERA 2005) in 1990 with its LCA subsection. Key motivation for KYOCERA's LCA engagement is the enforced utilisation of non-energy intensive manufacturing processes and supplier products. In order to achieve this goal, a company internal 'Environmental Consciousness Evaluation System' has been recently launched involving all company divisions (Procurement, R&D, Engineering, Manufacturing, etc.) (KYOCERA 2006). Using LCA as a quantitative evaluation tool, each product is analysed concerning its environmental consciousness from cradle (from the planning step) to gate (until and including the sale step). Accordingly, environmental data are continuously monitored at various stages along KYOCERA's value chain. That also includes KYOCERA's requirement that suppliers produce in conformity with environmental legislation (in particular with European rules) and that environmental audits are performed.

Adopting the LCA method since the late 1990s, ERICSSON seeks to detect significant environmental aspects associated with the manufacturing and the operation of its products (ERICSSON 2005). In response to the upcoming EU-directive on eco-design requirements for energy using products (CEC 2005b), a key intention of ERICSSON is the overall optimisation of the environmental performance of mobile phone networks with respect to energy consumption and CO_2 generation. The scope of LCA application at ERICSSON includes the raw materials, suppliers, transportation, mobile phone user as well as network operator activities and EoL-treatment. Results of LCA analyses are preferably used in the design of network components.

[3] A weighting is not mandatory.

NOKIA has been active in the development of LCA since the mid 1990s (Nokia 2004, Singhal 2005a). NOKIA's perception of LCA can be described as somewhat ambivalent: on the one hand, LCA is recognised as being able to be "suitable, for example, for: Strategic environmental assessment of new technology or business model..." (Singhal 2005a). On the other hand and in the same context LCA is described as being "not well equipped for making comparisons over different products" (Singhal 2005a)[4]. To facilitate a quantification of the environmental performance of, in this special case, electronic telecommunication products, a consortium under the auspices of NOKIA has developed the so-called Key Environmental Performance Indicators (KEPI) (Singhal 2005a, Singhal 2005b, Singhal et al. 2005). According to this approach the KEPIs basically rely on LCA (Scharnhorst 2006b, Singhal 2005a) taking, however, "The weaknesses of LCAs as inherent in the KEPIs" into account (Singhal 2005a).

At the operational level the SWISSCOM continually performs LCA studies in order to improve the overall environmental performance of the company and to provide the network component suppliers, such as ERICSSON, with relevant environmental data (Swisscom 2005, Swisscom 2006). In its efforts SWISSCOM focuses on energy consumption and the related CO_2-emissions, for example, as well as on the emission of electromagnetic waves, and strives to assess which life cycle phase represents the largest environmental impact and which activity causes that impact. The findings are mainly used to compile measures to either eliminate or, at least, reduce the impact of the identified source (Scharnhorst 2006a).

The British VODAFONE participated in LCA-related activities (Vodafone 2005). Based on the findings, the VODAFONE group has taken initiatives with respect to take-back and reuse of mobile phones and seeks to implement achieved LCA research findings in collaboration with the associated operating companies.

2 State-of-the-Art LCA-Applications

2.1 User terminals

One of the first analyses of the environmental effects associated with mobile phones was put forward as a contribution by the industry to the incipient debate on the recycling of mobile phones. Recognising the public awareness concern-

[4] This statement does not take into account that only products with the same functions can be compared. Products with different functions cannot be compared ISO (2005a): ISO 14040: Environmental management – Life cycle assessment – Principles and framework. International Organisation for Standardisation, Brussels.

ing the environmental implications associated with electronic devices and electronic scrap and in order to express the industries perspective on EoL-treatment of electronic scrap, a consortium of mobile phone manufacturers under the auspices of the European Trade Organisation for the Telecommunications and Professional Electronics Industry (ECTEL) set up a working group in the mid 1990s with the aim of studying the industry driven **collection and redistribution mechanisms for cellular phones** (ECTEL 1997). Two different take-back schemes were developed for two countries, one comprising the return of old mobile phones via surface mail or via outlet stores (Great Britain), the other one considering the take-back via the evacuation of mixed loads of non-perishable goods by trucks (Sweden). The analysis shows that the reverse logistics are of high importance concerning energy savings (Clift 1997, McLaren et al. 1999). However, and as indicated by the associated study (Clift et al. 2000), both take-back and recycling schemes are demonstrated to be uneconomic when compared with direct disposal of mobile phone scrap.

By extending Unilever's Overall Business Impact Assessment (OBIA) approach and by applying it to the production and the EoL-phase of mobile phones, Clift and Wright (2000) studied the interdependencies between **environmental effects and added values along the supply chain**. Principally, the OBIA-approach showed that the later a certain stakeholder (be it a hardware or a service supplier) is positioned in the supply chain of a mobile phone, the higher the added value and the less the addition to the total environmental burden. To demonstrate the analogy between the primary raw material manufacturing industry and the recycling industry, three scenarios (scenario *i)*: base scenario, no recycling but direct landfilling of mobile phone scrap; scenario *ii)*: re-use of used electronic components of an old mobile phone in a new mobile phone and scenario *iii)*: mechanical demolition, fractionation and finally re-use of secondary raw materials in a new mobile phone) were developed. The results indicate, despite the environmental superiority of recycling and re-use, that these alternatives are more costly than direct disposal without any recycling (ECTEL 1997, McLaren et al. 1999). Based on the findings, the authors claimed for interventions in the market in order to realise the environmental benefits associated with environmentally sound EoL-treatment.

Adopting the Environmental Engineering (EE-)toolbox developed by the Fraunhofer Institute IZM, Oiva et al. (2000) performed a **case study on the environmental impacts of a mobile phone**. The focus of the study was dedicated to the identification of the environmentally relevant components in order to identify design optimisation potentials. An LCI comprising a reduced bill of materials of a mobile phone was compiled and components of comparable type and package were aggregated to one average component. The results document that heavy metals, such as copper, nickel and lead (and their compounds), possess the largest toxic potential, thereby implying an increased environmental priority to recycle these metals. The authors briefly address that issue arriving at the conclusion that pure incineration and/or landfilling mobile phone scrap to get rid of it is not the environmentally preferable solution.

An LCA concentrating on an **analysis of the energetic and material flows** associated with the production, retail, use, take-back, recycling and final disposal **of a mobile phone** was performed by the RANDA consulting group (RANDA-GROUP 2000). Spanish conditions were presumed for the system under study and the average service life of a mobile phone was set to two years. The emphasis of the study was dedicated to the production phase and, for the sake of transparency, this phase was divided into the subsystems: production of alloys and plastics, manufacture of electronic components. A comprehensive LCI was compiled concentrating in particular on the rechargeable battery. In accordance with Tan (2005), the impact assessment revealed that the production phase dominates the use phase significantly. However, in contrast with any other LCA on mobile phones (or including these components in a network analysis), the authors found that the environmental impacts of the battery dominate the effects of all other components. Based on the findings, and facing the EU regulations on minimisation of electronic and electric waste (WEEE) and the substitution of hazardous substances in electric and electronic devices (RoHS) upcoming at that time, the authors recommended the expansion of environmental analyses on electronics and the promotion of ecodesign.

Aiming at the **identification of improvement strategies for electronic products,** the Canadian National Office of Pollution Prevention performed an LCA project in close collaboration with Nortel (NOPP 2000). The goals of the project were twofold: evaluation of the applicability of LCA for the assessment of the environmental effects of a phone (here: of a wired phone) and, on the other hand, the formulation of guidelines for environmental design improvements for next generation electronic products. The system under study comprised all life cycle stages, i.e. production, use and EoL-treatment and was performed for Canadian conditions. Different scenarios were developed in order to assess the environmental consequences of alternative product assemblies (different keypad technology, thin-walled plastic housing and different EoL options). The key results of the project indicate that the energy consumption during the use phase dominates the overall environmental impact of the user terminal. The manufacturing of the Integrated Circuits (ICs) dominated the environmental impact score in the production phase. Analysing the scenarios showed that neither the proposed new keypad technology nor the thin-walled phone housing could contribute to reduce the overall environmental impact score. More generally, the authors report that LCA could be reliably applied to assess the environmental effects of electronic products. In order to balance the environmental aspects and commercial management interests, the researchers claimed to link LCA with economic analysis methods.

Concentrating exclusively on the **EoL-treatment of mobile phones** and other wireless user terminals, Fishbein (2002), in a very comprehensive environmental report, investigated the available state-of-the-art EoL treatment practices, compared the practices applied in different regions of the world with each other, identified existing environmentally critical aspects and approximated environmental problems for the near future. Goal of the underlying study was to assess the

waste problems posed by cell phones and wireless devices and to collect recommendations concerning how these problems could be eliminated in the production phase. Following an extensive introduction on mobile phone standards and market shares, Fishbein compiled a nearly exhaustive list of substances and elements deemed to be environmentally critical. Subsequently, the EoL-management as applied in the US, Europe and Asia were analysed. The report was finished by a survey on available and future battery technologies and a rather general outlook on the future development of wireless applications. The insights obtained from the investigation gave reason to formulate some of the following recommendations (which today are partly realised and partly awaiting realisation):

- No further reduction of the size of user terminals such as mobile phones, because of the increasing susceptibility to be thrown directly in the dust bin and thus being lost for material recovery.
- Unification of mobile phone standards as the diversity of incompatible standards makes the acquisition of numerous mobile phones necessary[5].
- No introduction of disposable mobile phones, because this would further increase the waste stream.
- Substitution of persistent and bioaccumulative chemicals, for instance, those contained in flame retardants.
- Encourage consumer participation in take-back schemes[6].

In a brief analysis on the **environmental effects associated with** different **surface finishing practices applied to mobile phone housings** Jiaang-Xin et al. (2004) performed a cradle-to-gate LCA. Based on energy production data adopted from (Boustead et al. 1979) and housing processing data gathered from the concerned suppliers of the housing manufacturer, Jiang-Xin et al. showed that, out of the studied alternatives, the electroplating technique represents the environmentally least impacting alternative. However, the authors allude to the fact that electroplating may cause the release of heavy metals to water. Due to its distinct energy intensity, the vapour-deposited metal technique (VDM) was identified as the least preferable alternative. In addition, the VDM-technique required the application of more metals than the electroplating method.

The most recent investigation on the environmental effects associated with a mobile phone was performed by Tan (2005). Key objective of this bachelor-thesis was the formulation of recommendations concerning how to minimise the environmental critical effects determined for the whole **life cycle of a mobile phone**. The study was performed for three types of mobile phones differing in terms of age (7 years, 2 years and 2 weeks), equipment (Liquid Crystal Display (LCD) size, functionality), stand-by time, etc. Regionally, this study was delimited to the south-eastern Asian region and, in particular, to Australia. The average service life of a mobile phone was set at 2 years. In order to perform a state-of-the-art LCA complying with the ISO-standards Tan compiled in-depth mobile phone inventories including experimental measurements of the energy consumption in the use phase (charging) and a comprehensive analysis of the materials the mobile phone bodies consist of based on a previous breakdown of the individual mobile phone components. Overall, the impact assessment reveal that the fabrication of IC- and of PWB-components dominate the environmental effects of mobile phones. In contradiction to another study (Faist-Emmenegger et al. 2006), the author found that the environmental effects of the use phase does not dominate those of the production phase. The latter phase is dominated by the environmental effects related to auxiliaries, like chemicals, applied in the manufacturing of PWBs and ICs. Based on the findings, Tan suggests to further integrate ICs resulting in less components per PWB, which in turn would reduce the environmental effects associated with the production phase (less auxiliaries, less basic materials like metals) and the EoL-phase (reduced demolition time, less final waste). He further recommends the substitution of hazardous materials in the manufacturing of ICs.

[5] This is a particularity of the US.

[6] At the time the report was issued in Japan a fee levied on returned old electronic devices.

2.2 Operator infrastructure

The **Material Input Per unit Service (MIPS)** approach, originally developed by F. Schmidt-Bleek (Schmidt-Bleek et al. 1998), was used to illustrate the environmental burdens associated with the operation **of a mobile phone network in Italy** in a rather popular scientific manner (Federico et al. 2001). Based on an LCI covering material and energy input fractions and expressing all fractions in 'kg', the total mass flow was calculated. The results of the study indicate a mass flow of 0.207 kg per minute phone call and of 0.632 kg per short-message sent. In contrast to earlier studies (Grunewald et al. 1999), the results of the study show that the environmental effect of transport processes is only of minor relevance.

Graedel and Saxton (2002) applied a semi-quantitative (streamlined) LCA alternative primarily in order to detect **improvement capabilities of telecommunication management and supply services** and secondly to demonstrate the reasonability of the applied LCA approach for telecommunication services. Object of the investigation was a network installation and maintenance facility and a network management facility. A so-called semi-quantitative assessment matrix consisting of five life cycle stages was developed (facility development, service provisioning, service performance, facility operation and site and service closure) for which five factors (material choice, energy consumption, solid residues, liquid residues, gaseous residues) were considered. Based on a technical characterisation of the facilities under study, the corresponding factors were applied to the respective life cycle stages and ratings were assigned (0: highest environmental impact – 4: lowest environmental impact). The results of the study suggest that optimising the facility development stage (in particular solid residues and energy consumption), the service performance and the site and service closure stage (always energy consumption) represent the biggest improvement potentials of the network installation and maintenance facility. In case of the network management facility, the facility development stage possessed the largest improvement potential.

Performing an in-depth **LCA study for a single transceiver unit**[7] Grunewald and Gustavsson (1999) analysed the environmental effects associated with the EoL treatment of such a device. Taking into account the world wide distribution of transceiver units as well as the regionally different EoL legislation, the investigation was performed for European, US and Japanese conditions. Ultimate goal of the study was to determine the environmentally preferable EoL treatment alternative for a transceiver unit. In order to accurately model the EoL phase Grunewald and Gustavsson compiled comprehensive and region-specific EoL treatment scenarios including transportation, mechanical treatment (dismantling and shredding) and thermal treatment (smelting and incineration). The key findings of the study imply that a transceiver (just like other comparable products) should be processed in local EoL treatment facilities and should not be transported back to where it was produced. In particular, aeroplane transport should be avoided as, according to the study, this transport alternative dominates most of the impact categories such as air acidification, air toxicity, energy depletion, global warming, etc. Being in conformance with later studies (Malmodin et al. 2001, Scharnhorst et al. 2006a), the authors further conclude that mechanical, and often labour-intensive, pre-treatment (dismantling) of a transceiver prior to automated mechanical processing (shredding) does not contribute to reducing the environmental impact associated with the EoL treatment.

In order to assess the **environmental effects to be expected with** the implementation in mobile phone networks complying with the **third generation (3G) standard**, Malmodin et al. (2001) performed a prospective LCA study taking the findings of previous investigations (Grunewald et al. 1999, Weidman et al. 2001) into account. By developing a flexible LCA model, the key intention of the study was the qualitative and quantitative description of the environmental effects associated with Ericsson's 3G mobile phone networks. The system under study comprised the entire mobile phone network infrastructure, i.e. the NodeB (in the original study, the term 'Radio Base Station' was used.), the Radio Network Controller (RNC), the Mobile Switching Centres (MSC), etc., as well as the user-owned mobile phones. The LCI was realised applying a hierarchical approach and a so-called site concept. The impact assessment reveals that, in terms of energy consumption, the use phase dominates the impact of the production and the EoL phase (Malmodin 2004). In terms of network components, the NodeB contribute most to the impact of energy consumption and the manufacturing of the PWBA dominates the energy consumption on the production phase. Overall, the EoL phase is estimated to have no effects, neither negative, i.e. the environment harming, nor positive, i.e. reducing the environmental effects of, for example, the production phase.

By comprehensively reviewing the pertinent literature on mass and energy consumption associated with the production, operation and EoL treatment of Information and Communication Technology (ICT) devices, and based on a taxonomy of rebound effects earlier developed for the energy sector (Greening et al. 2000), Plepys (2002) sought to demonstrate the **rebound effects between energy supply and the growing environmental effects of ICT**. Analysing the four-tier rebound effect taxonomy of Greening et al. (2000), Plepys concludes that the particular environmental relevance of ICT devices is rooted in higher order rebound effects comparable with economy-wide and transformational effects in the energy sector at a macro level. He exemplary demonstrates this relevance for office paper, digital media and the rebound effect associated with e-commerce and teleworking. In conclusion, Plepys claims a far-seeing utilisation of ICT products.

Estimating and comparing the **environmental effects of a GSM and of a UMTS network** the next study was dedicated to assessing the differences in the environmental effects associated with networks complying with the two standards (Faist-Emmenegger et al. 2004). Based on a separation of the networks into network subsystems and components, the environmental effects were quantified for Swiss conditions and per data transfer from mobile phone to mobile phone and mobile to fixed phone, respectively. The results of the study indicate that the mobile phones dominate the environmental effects of all mobile phone network components. It is also shown, in the case of GSM as well as of UMTS compliant mobile phones, that the use phase dominates overwhelmingly the impact score of the production and the EoL phase. A finalising sensitivity analysis demonstrates the relative importance of the use time of a mobile phone on the environmental effects, which nearly halves when expanding the use time from one to four years. With respect to the consumption of (precious) materials in the production phase, the authors recommend an improvement, in particular of the manufacturing of PWBA. Finally, the authors urgently suggest optimising the energy consumption of the mobile phones as well as of the network components.

Taking the widely acknowledged environmental relevance of the EoL phase into account (Rebitzer et al. 2004) and aiming at an in-depth analysis of the **environmental effects related to the EoL treatment of a mobile phone network component**, Scharnhorst et al. (2006a) performed gate-to-grave LCA on the treatment of an antenna rack as used in GSM-compliant BTS. Based on a thorough analysis of the state-of-the-art EoL treatment techniques as encountered in Western Europe, the EoL phase was decomposed in eight successive process stages ranging from rack dismounting at the BTS site to the final disposal step. The environmental consequences associated with different EoL-treatment strategies were investigated by developing six EoL treatment scenarios. In order to consider the different amounts of regained materials, the system under study was expanded to include the production phase. The results of the study indicate that direct disposal of a BTS rack represents the environmentally worst alternative[8]. Similarly, as earlier denoted by Grunewald and Gustavsson (1999), the analysis proved that mechanical pre-treatment prior to thermal EoL treatment for metal recovery does not contribute to lower the environmental impact score. Based on the results, the authors recommend

[7] Transceiver units (TRX) manage the transmission of radio waves and are installed at the Base Transceiver Station (BTS) sites.

[8] The direct disposal option was selected as an extreme case.

performing state-of-the-art EoL treatment without mechanical pre-treatment and suggest the recovery of particularly precious metals in appropriately equipped facilities. In order to further lower the overall environmental impact score of BTS racks, the authors recommend the prolongation of the effective use time.

The objective of one of the most recent LCA studies on mobile phone networks was the reliable analysis of the **environmental effects of mobile phone networks complying with the GSM-standard**, on the one hand, **and the UMTS-standard** on the other hand (Scharnhorst et al. 2006b). Key intention was to perform an LCA study that for the first time relied as often as possible on actual network statistics as on professionally estimated prognoses. That included also a network modelling in compliance with the authoritative mobile telephony standards issued by the European Telecommunications Standards Institute (ETSI). Life cycles of mobile phone networks complying with the GSM-standard (GSM, GPRS (General Packed Radio Service) and EDGE (Enhanced Data Rates for Global Evolution) and the UMTS standard (UMTS Release 1999 (R'99; UMTS-FDD), UMTS Release 2004 (R'04; UMTS-FDD/TDD), UMTS Release 2006 (R'06; HSDPA/HSUPA)) were modelled based on a decomposition of the networks, a top-down classification of the individual network components, the definition of base components (for instance, PWBA, housings, etc.) and the inventory of mass flows and emissions for these components followed by a network parameterisation and recomposition of the mobile phone network. The results of the impact assessment indicate, in terms of impact per functional unit at present, that UMTS compliant networks possess an environmental performance worse than that of GSM-networks. However, due to the significantly larger data processing abilities offered by the UMTS-technology and considering the expected growing data traffic, it is expected that future UMTS-networks will perform environmentally better than GSM-networks. In terms of absolute environmental impacts, UMTS-networks (R'04) performed slightly better than GSM-networks applying the most advanced EDGE technology. However, the environmental impacts are expected to increase as the extension of the UMTS-network infrastructure proceeds and the penetration with user-owned terminals rises. It is shown that the EoL phase could contribute to significantly compensate the environmental effects related to the production phase (which otherwise and together with the use phase dominate the environmental impact scores). In conclusion, the authors recommend that the transition phase from GSM to UMTS technology should be kept as short as possible, that the energy consumption of the radio network components needs to be lowered, and that, in particular, the manufacturing of the PWBA should be analysed with respect to potentials for energy savings.

2.3 Companies

Only one study could be found considering the application of **LCA to a telecommunication company** (Gotthardt et al. 2005). Therein, Gotthardt and colleagues sought to quantify the environmental effects of an entire telecommunication corporation, including indirect aspects, and to define recommendations for improvements. The system under study included the suppliers providing services for company processes (e.g. electricity suppliers) as well as suppliers of products for the use phase (e.g. mobile phone manufacturers). As a core issue, the system further covered processes provided by the analysed telecommunication company for the use phase of the products (i.e. the transmission of voice and non-voice data via the mobile phone network). Finally, the study comprised the EoL treatment of company related waste as well as of the user-owned devices. The results of the study indicate that in terms of energy consumption the supply of electricity to charge the user-owned devices dominates the energy consumed to operate the backbone telecommunication network owned by the corporation. The impact score of the services offered by the corporation is dominated by the internet services followed by mobile phone and fixed phone services. The study further demonstrated that the environmental effects related to Internet and mobile communication services are dominated by the production phase and not by the use phase. Conversely, the impact score of the use phase dominates the environmental impact score of fixed phone service. The environmental impact of the production phase was negligible. In order to improve the overall environmental performance of the analysed telecommunication corporation, the authors suggest introducing criteria for low consumption devices and environmental-friendly product compositions. Finally, the corporation is suggested to offer a range of attractive, low energy consumption, user terminals.

2.4 Personal computers & PWB(A)

One of the first in-depth studies on the environmental effects associated with the EoL-treatment of personal computers (PC) was performed by Randall Conrad (2000) on the **recycling of waste from computers**. Reflecting on the situation in the Canadian province Alberta, the author determines the following key issues: the toxicity of components, the increasing amount of electronic scrap and the missing recycling infrastructure. In order to analyse these aspects, the author compiled extensive inventories on the amount of PCs owned by households, the amount of electronic scrap now and then, and finally the different materials contained in a PC. Accordingly, this document represented, at its time, one among a few state-of-the-art sources when looking for comprehensive material inventory data of PCs. Compiling different theoretical aspects, the author discusses the various advantages and disadvantages of different EoL treatment options and the particularities imposed by metals (promotion of furan and dioxin formation during thermal treatment) and PVC (promotion of the formation of volatile heavy metal compounds being environmentally critical). Based on these insights, Conrad suggests reducing the amount of materials built in a PC by modularising the different PC components, to reuse obsolete PCs (or components), and to recycle electronic scrap.

Associated with the advent of the era of LC displays used as periphery equipment in ICT infrastructure, new environmental concerns arose. In order to analyse the assumed environmental effects of LC displays, Socolof et al. (2005) performed

a comparison of the **environmental effects of cathode ray tube (CRT) and LC desktop computer displays**. Goal of the study was the establishment of a scientific baseline to evaluate the life-cycle related potential environmental effects of CRT and LCD screens. The results indicate, with a few exceptions, that the environmental impact score of the CRT screen is almost always one order of magnitude higher than that of a LC display (renewable resources, energy use, solid waste, hazardous waste, radioactive waste). Only in the cases of aquatic and terrestrial eco-toxicity is the impact score of the LC display larger. Comparing the different life cycle phases with each other indicated, in terms of energy consumption, that the manufacturing phase clearly dominates the impact score of the use and the EoL-phase. Most of the manufacturing related impacts (of the CRT screen which dominates the LC display in terms of overall environmental impact scores) are attributable to the energy intensive CRT glass manufacturing. In terms of global warming, the use phase dominates the other life cycle phases in case of the CRT screen as well as of the LCD. From the findings of the study, the authors recommend optimising the energy consumption of the CRT in the use phase. Concerning the LCD, the authors suggest analysing and optimising the application of SF_6 and natural gas as well as the energy demand of the LCD in the use phase.

Performing a simplified LCA, Almborg et al. (2001) compared the **environmental consequences of surface and hole mounted resistors** with each other. Covering all life cycle phases (production, use and EoL treatment), but excluding any kind of emissions to air, soil and water, the authors found, in terms of depleting natural resources, that surface mounted resistors perform environmentally much worse than hole mounted resistors. In particular, the energy intensive manufacturing of surface mounted resistors accounts for the large environmental impact score.

In another brief study, Davidsson et al. (2001) compared the **environmental effects of plastic and paper capacitors**. Covering only some metal extraction processes, transportation and EoL treatment, the authors found that the transportation processes dominate the overall environmental impact score. It has also been assessed that incineration of capacitors during the EoL-phase would contribute to a significant extent to an increased overall environmental impact.

Adopting an earlier developed LCI approach, Andrae et al. (2004) investigated for the first time the **environmental effects associated with the manufacturing of a System-in-a-Package (SIP) switch product**. Goal of the study was the identification of environmentally relevant processes in the supply chain processes. In order to illustrate the technological development from an environmental perspective, the authors compared the results obtained for the toxicological assessment of the switch product under study with those results obtained for a digital telephone. Overall, the results of the study indicate that the energy and solvent intensive, spin coating of the photoresistant material dominates the environmental impact score of the switch board. To a minor degree, also deposition (energy consumption) and exposure processes contribute to the environmental impact score. The toxicological assessment indicates a large value for the switch per mass unit, which in turn was significantly higher than the value obtained for the digital phone. Based on the results and due to the identified lack of knowledge on other packaging strategies, the authors recommend the complementary performance of further studies on other packaging approaches.

In response to the steadily increasing debate on environmental effects associated with the EoL treatment of electronic components and emphasizing the economic aspects of recycling, Goosey and Kellner (2002) performed a **scoping study on the EoL treatment of PWBA**. Reviewing the technological situation at the end of the 1990s, as encountered in different regions worldwide and in particular in the UK, the authors tried to determine environmentally less critical EoL treatment alternatives than final disposal in landfills. Based on a thorough modelling of the EoL phase and a likewise thorough quantitative inventory of the PWBA materials, it is shown that the majority of the PWBA scrap is derived from the final product manufacturers, like mobile phone assemblers, and not from PWB manufacturers and from end-users. The smallest fraction stemmed from dismantlers. In the following, the authors present and discuss new and emerging EoL technologies like mechanical approaches (mainly focussing on particle separation), hydrometallurgical (for fractionation) and thermal treatment, i.e. smelting. Based on the review of the existing and the analysis of the upcoming EoL treatment technologies, the authors recommend recycling as the option of preference. They motivate it first of all with a reduction in landfill disposal demand and the recovery of precious secondary raw materials. Documenting the economic values of the recovered, secondary raw materials, the recommendation for EoL treatment including dismantling, recovery and recycling of electronic scrap is motivated from the economic perspective. From a technical perspective, the authors conclude that hydrometallurgical methods could represent an alternative to maximise the recovery of intrinsic metal value such as of precious metals.

Taking up the debate concerning lead in solders, Suganuma (2001) analysed in detail the technological **advances in lead-free soldering** concentrating on Sn/Ag/Cu, Sn/Zn/Bi, Sn/Cu and Sn/Bi/Ag solder alternatives. By analysing in-depth the metallurgical aspects of lead-free solders (e.g. phase diagrams, microstructures, wetting nature, interface microstructures as well as solidification, lift-off, creep and fatigue), Suganuma arrives at the conclusion that, from a technological perspective, Sn/Ag/Cu solders represent the preferable alternative. The finding is motivated with the excellent interface bonding and mechanical properties of this solder alternative. Restrictively, the author relativises the overall meaning of the finding as too little is known on the behaviour of this (as well as other lead-free) solder alternative(s) in the various electric and electronic environments (e.g. PCs, mobile phones).

Within the frame of the Lead-Free Solder Project, organised by the Center for Clean Products and Clean Technologies (http://eerc.ra.utk.edu/ccpct/lfsp-projectinfo.html), and concentrating on the European regulative conditions (CEC 2003a, CEC 2003b), Kindesjö (2002) performed a theoretical analysis on the possible **environmental consequences associated with the transition from lead-containing to lead-free solders when it comes to the EoL treatment of PWBA.**

To achieve this goal, and based on extensive literature research, Kindesjö investigated the common component mounting technologies of Surface Mount Technology (SMT) and Through Hole Technology (THT) (Klingenstein et al. 2004) in a first step, followed by a compilation of the technical and environmental characteristics of metals as applied in the following five different solder pastes: Sn/Pb (63%/37%), Sn/Cu (993%/0.7%), Sn/Ag/Cu (95.5%/4.0%/0.5%), Sn/Ag/Bi (42%/1.0%/57%) and Sn/Ag/Cu/Bi (92.3%/3.4%/1.0%/3.3%). Based on a comprehensive analysis of the available EoL treatment technologies for electronic scrap, Kindesjö traced the route of the solder and where it eventually ended up. The results show that, appropriate filter technologies presumed, most of the lead is retained in gas dust filters[9] and that no obvious threat to workers in recycling plants exists. Kindesjö found that, at present, only one quarter of the metal containing dust is recovered from loaded filter equipment. The remaining filter dust is disposed of representing a major loss of valuable raw materials and a potentially environmental threat when it comes to leaching of heavy metals from the landfill site. Compared with the other, lead-free solders, Kindesjö states in summary that, from an environmental as well as from an EoL-technical perspective, it would be preferable to switch to solders based on copper and silver, as these materials are typically recovered during thermal EoL-treatment. However, the author relativises this finding stating that the fractions of Cu and Ag in lead-free solders are small compared with that in the Sn fraction. Thus, the majority of the solder material is still lost during EoL treatment. From a purely technical point of view, the findings of the study showed that bismuth can be a reason for increased impurity of the copper cathodes produced during thermal EoL treatment[10]. Similar technical problems can be caused by too high a tin load, thereby disturbing the extraction of metals trapped in the filter dust. From an economic viewpoint, Kindesjö shows that solder pastes containing silver in larger fractions would pose a recycling incentive. In essence, the author recommends replacing lead-containing solders by solders containing metals which are effectively recyclable (e.g. Sn/Ag/Cu), which is in agreement with the technological findings of Suganuma (2001) discussed above.

Taking the permanent technical and technological development in the telecommunication sector into account, Uryu et al. (2003) quantitatively assessed the **environmental fate of gallium and arsenic released from disposed semiconductors**. Performing a basic elemental analysis of the thermal treatment of GaAs semiconductors, simulating the distribution of gallium and arsenic in the air emissions and performing leaching experiments, the authors found that the majority of gallium (99.8%) as well as a significant amount of arsenic (80.3%) are retained in the incineration residuals. About 1.58% (Ga) and 19.5% (As) are leached to water. Based on the findings, the authors suggest omitting the incineration of GaAs containing semiconductors in Municipal Solid Waste Incineration plants, and to directly landfill that fraction of semiconductors that cannot be successfully treated in metal recovery plants.

[9] Kindesjö gives a value of 99.2% for the filter efficiency with respect to Pb.
[10] Kindesjö gives a value of 99.998% purity for copper cathodes.

In a recent effort, Scharnhorst et al. (2006c), analysed the **partitioning of heavy metals from electronic scrap during thermal EoL treatment**. Objective of the study was to formulate recommendations for environmentally sound thermal EoL treatment on the basis of analysing the formation of volatile heavy metals. To achieve this aim, identical PWBA were collected and manually and mechanically chopped and separated into homogenous samples. Subsequently, these samples were thermally treated under reducing as well as under oxidising conditions and at 550 and at 880°C. In addition to the oven experiments, evaporation experiments (using a TG-ICP-OES (Thermo-Gravimeter in connection with an Inductively Coupled Plasma – Optical Emission Spectrometer)) as well as thermodynamic equilibrium calculations were performed. The results of the study indicate that As, Cd and Ga are completely removed from the bottom ash. Ni is completely retained. The volatility of Pb decreases with increasing temperature under oxidising conditions and increases under reducing conditions. The volatility of Sb drops under any oxygen supply conditions with increasing temperature and the volatility of Zn is assumed to decline under oxidising conditions and with increasing temperature and to incline with raising temperature under reducing conditions. Based on the findings, the authors claim that reducing conditions should be avoided during thermal EoL treatment of electronic scrap and that appropriate filter techniques are applied. In context with the latter aspect the authors recommend being careful with respect to technology transfer to developing countries. Often, these countries do not possess the appropriate filter techniques to perform environmentally safe thermal EoL-treatment and, thus, technology transfer, though well meant, can be a source for increased environmental impact.

3 Criticism in Summary and Recommendations

The presented review, though not claiming to be exhaustive, recapitulates the progressive evolution of LCA in the field of telecommunication products during recent years. It illustrates how approaches, viewpoints and perceptions have been altered based on scientific evidence. However, in order to propel and motivate further research actions in the field of LCA in general and with respect to telecommunication business in particular, the following key criticisms need to be formulated:

- The formulation of a clear goal and scope is compulsory for a successful, reliable and comprehensible LCA. Otherwise, LCA studies do result in biased or incomprehensible findings, in turn leading to measures that again can cause increased instead of mitigated environmental consequences. Though assumed to be admitted throughout the LCA community, studies like those of Almborg et al. (2001), Davidsson et al. (2001) and the RANDA-Group (2000) prove the opposite.
- There is an urgent need to involve all concerned stakeholders in planning, designing and adjusting the goal and scope of an LCA. An example for excellent stakeholder involvement may be the study performed by Gotthardt et al. (2005) as well as the study of Kindesjö (2002). Publicly available LCA studies such as the one of Malmo-

din et al. (2001) certainly add interesting stakeholder insights, but are suspected of being too biased.

- If it comes to complex products like mobile phones, consisting themselves of sub-products, which may, in turn, again consist of sub-products, there is a need for a well-balanced LCI as, for instance, excellently compiled by Conrad (2000) for personal computers and by Scharnhorst et al. (2006b) for GSM and UMTS networks. Inventories consisting of very exact, detailed and comprehensive data for a sub-product A, but consisting only of a few rough approximations for a sub-product B and C, do entail biased results, in turn leading to biased interpretations. This problem can be retraced from the study performed by the RANDA group (2000) which concentrated on the life cycle assessment of a mobile phone, but due to data gaps actually performed an LCA for mobile phone batteries resulting in the conclusion that the batteries dominate the environmental impact score of mobile phones.
- The same holds true for the life cycle phases. For example, omissions of the production and the use phase and including merely transport processes as well as the disposal of aluminium in the EoL-phase, for example, inevitably result in the conclusion that the transportation processes dominate the environmental effects of an electronics component life cycle (cf. (Almborg et al. 2001, Davidsson et al. 2001)).
- Most LCA studies, and this is typical in particular for electronic products, suffer in general from a weak data basis or the availability of nearly outdated data. From the authors own experience, there is an urgent need to facilitate the flow of required information. Another option that should, whenever possible, be taken into account, is the standardised experimental analysis of the life cycle processes of telecommunication equipment in order to improve the data reliability and to better understand the processes. A first step in that direction has been undertaken by Tan (2005) who measured energy demands to recharge batteries experimentally and by Scharnhorst et al. (2006c) where PWBA were treated thermally in order to detect the volatilisation of heavy metals.
- The review shows that there exist two perspectives concerning the environmental relevance of the EoL phase within the overall life cycle of electronic products. There exist reports that neglect any relevance (Faist-Emmenegger et al. 2004, Malmodin et al. 2001) and there exists the opposite (CEC 2003b, Fishbein 2002, Scharnhorst 2005, Tan 2005). Under the present conditions of scarcity and cost intensity of, in particular, precious metals like gold, silver, palladium, but also of aluminium and of copper, the quantitatively demonstrated potential of the recovery of these and other materials should be considered in LCA studies on electronic products.
- Finally, it is evident that telecommunication networks represent complex structures that are difficult to model. However, most, if not all, of these kinds of structures are based on technical standards (ETSI 1996, ETSI 1999, ETSI 2001, ETSI 2003b)[11]. A life cycle modelling of such networks according to the valid standards including component assembly, network structure, transmission modes and rates, etc., for example, as well as the consequent use of the defined terminology (as, for instance, applied in Scharnhorst et al. (2006b) and not as unfortunately discovered in Faist-Emmenegger et al. (2004)) would facilitate both a transparent life cycle assessment and a trouble-free application of the achieved study results to assist, for instance, in decision-making processes of a telecommunication company.

In order to overcome some of the identified problems and to improve the reliability of LCA in the context of telecommunication equipment, the following recommendations are formulated:

- A process-backbone of the system under study should be specified comprising a defined number of processes[12] that are mandatory for inclusion and thereby provide for a least achievable quality of system modelling in context with the pre-defined **goal and scope**. If data or information of processes that belong to the process backbone is unavailable, either the focus of the study has to be adjusted or the study cannot be performed.
- In order to perform LCA studies for **technically nested products** (like mobile phones, PC, or networks), a top-down decomposition is suggested. This provides a systematic way to discover data needs, to compile the inventory, to assess the impacts and to interpret the results. Furthermore, such a systematic approach is assisted, for example, by the valid technical standards mentioned earlier that, for example, clearly describe the configuration of the telecommunication equipment under study.
- **Stakeholder involvement** is indispensable when trying to perform LCA (in general, and with respect to telecommunication products in particular). This can be improved by clearly structuring and tailoring the study according to the needs of the concerned stakeholder(s). A separation of issues specific only for a certain involved party can be of advantage (for instance a mobile phone network operator is primarily interested in the effects related to the use phase of the network components).
- One way to solve the often cited **data quality** problem is certainly a closer stakeholder involvement. That includes two tasks: on the one hand, the LCA researcher needs to continuously attract the interest of the concerned parties (industry, government, etc.) by justifying data needs and pointing out the reductions in the quality of the study if data remain unavailable. On the other hand, the industry in particular needs to clearly understand that products that are sustainable (sustainable in any context: quality, quantity, sales, environment, legal, etc.) are only developable, producible, marketable, maintainable and finally recyclable based on comprehensible understanding of the effects associated with it.
- The preceding recommendation does not necessarily result in a permanent excess of man power, cost and other efforts. Instead, if **LCA** is associatively and **continuously**

[11]Only a limited selection of standard references is quoted here. All of them are available for free at ETSI (2003a): ETSI Publications Download Area. ETSU, http://www.etsi.org.

[12]For example, production, use, or EoL-related processes depending on whether cradle-to-gate, gate-to-gate, gate-to-grave or cradle-to-grave studies are concerned.

performed at the research & development level (cf. (Clift et al. 2000)) and taking benefit of the experiences from all other company departments (in this context further development at KYOCERA would be very interesting), avoidable environmental effects, and thus the associated costs, can be avoided.

4 Conclusions from Past Research in LCA

The present review attempts to compile and to reflect the key milestones achieved in the development of LCA when applied in the telecommunication industry. Concluding from the findings of the review, it has been recognised that neither the analytical potential of LCA nor the possibilities for further development of the method are fully discovered and utilised. Approaches to simplify, i.e. streamline, the LCA method are numerous (the above-mentioned EE-toolbox of the Fraunhofer IZM or the KEPI-approach of NOKIA are just a few). However, to date only few of such developments have prevailed. Other approaches like the 'Stoffgeschichte'-method (Reller et al. 2006) developed to comprehensively understand the origin and the life cycle of metals (presently) within a global context seem to miss the universality of LCA.

All in all, it can be stated that ISO-conform LCA represents a promising alternative to analyse, to interpret and essentially to adjust the environmental performance of electronic telecommunication products and concise further development of LCA should continue at the roots of the method, including even a modification beyond the valid ISO-standards.

5 Outlook and Challenges

The conclusions from the presented review suggest concentrating in particular on a further development of the LCA methodology with respect to efficiency, effectiveness and flexibility. This challenge is associated with the need for LCA to be understood as a process, rather than a discontinuously applicable tool, attending industrial processes to, in essence, contribute to improved environmental performances of products. In this context, particular attention should be paid to proper stakeholder involvement and continuous exchange of concentrated information relevant for the respective stakeholder.

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